Magnetization Transfer Effects in Wideband SSFP

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INTRODUCTION: Wideband SSFP (wbSSFP) is an alternating TR SSFP sequence that provides increased band spacing compared to conventional SSFP [1,2]. Like balanced SSFP (bSSFP), wbSSFP provides high signal-to noise efficiency and T_2/T_1 weighting. It has recently been shown that the signal intensity of bSSFP is strongly affected by magnetization transfer (MT) effects [3]. There has also been recent evidence that wbSSFP provides superior depiction of spinal nerves, enabling tracking of nerves well outside the dura, and may be a powerful new tool for MR myelography [4]. Motivated by these findings, we explore the influence MT effects in wbSSFP and found these effects to be more significant than in conventional bSSFP.

METHODS: MT effects in most biological tissues can be simulated using a "two-pool" model [5], and by either solving coupled differential equations [6,7], or partially integrated Bloch equations [6,7]. We modified the latter approach to study MT effects in wbSSFP compared to conventional bSSFP. Numerical simulations were performed in MATLAB to assess the MT ratio (MTR) of wbSSFP and bSSFP as functions of flip angle (α) and of RF pulse duration (T_{RF}). We used RF waveforms similar to those used in 2D and 3D bSSFP imaging on commercial scanners, with nominal T_{RF}=640μs, and time-bandwidth product of 1.5. White matter was simulated assuming T_{1f}=585ms, T_{2f}=85ms, T_{1r}=1000ms, fractional pool F=0.156, and exchange rate k_r=4.5/F(s^{-1}), as published in Ref. [6]. The mean saturation rate (W) was also calculated according to Ref. [6]. We modeled wbSSFP with TR/TE=6.4/2.1ms, TR_s=2.2ms, as in Ref. [4], with signals only collected during the long TR; bSSFP parameters were TR/TE=6.4/2.1ms. The MTR was computed, in percentage units, according to:

$$MTR = 100\frac{\langle S(W_{\min})\rangle - \langle S(W_{\max})\rangle}{\langle S(W_{\min})\rangle}(\%)$$

where $\langle S(W_{\min})\rangle$ and $\langle S(W_{\max})\rangle$ are the SSFP signals, averaged over 2/3 of the passband, with minimum and maximum saturation rates, respectively. In Figure 2, W was modulated by flip angle; in Figure 3, by T_{RF}.

RESULTS: Figure 1 shows the simulated steady state wbSSFP signal profiles for white matter with and without MT effects. The average passband magnetization is attenuated by 30% due to MT. Figure 2 compares MTR(α) for wbSSFP and bSSFP over a range of flip angles. Figure 3 compares MTR(T_{RF}) for wbSSFP and bSSFP at various RF pulse durations. The MTR in wbSSFP is larger than that of bSSFP at all α and T_{RF}.

DICUSSION: From this data, it is clear that MT effects are more pronounced in wbSSFP compared to bSSFP. This is partially a consequence of increased RF power per unit time; however, our simulation results (not shown) indicate that even with the same RF power per unit time and with the same passband width, the MT effects in wbSSFP are still lager than in bSSFP. We believe this is due to the fact that the magnetization vector in the steady state has larger amplitude in wbSSFP compared to bSSFP [1], and therefore the available longitudinal magnetization prior to RF excitation is also longer. Next steps include in-vivo testing of this observation, and similar studies for the broader class of alternating-TR bSSFP sequences [2].

CONCLUSION: Wideband SSFP is more sensitive to MT than bSSFP. This contrast may be exploited to generate sensitive MTR maps or to acquire images with strong MT weighting.

REFERENCES: [1] Nayak KS *et al*, MRM **58**: 931 (2007); [2] Leupold *et al*, MRM **55:** 557 (2006); [3] Bieri O *et al*, MRM **56**:1067 (2006); [4] Schmidt EJ *et al*, Proc. ISMRM, p. 448 (2010); [5] Sled JG *et al*, MRM **46:** 923 (2001); [6] Gloor M *et al*, MRM **60:** 691 (2008); [7] Gloor M *et al,* MRM **64:** 149 (2010).

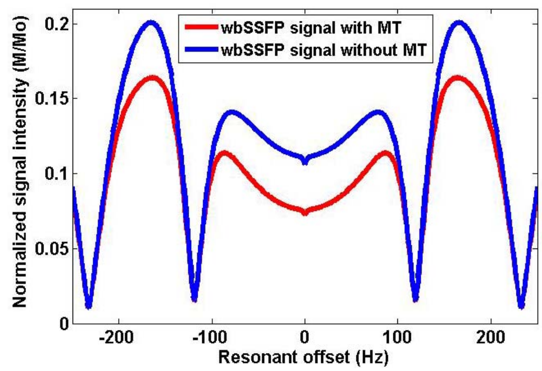

Figure 1: *Simulated white-matter wbSSFP signal as a function of resonant offset with and without consideration for MT effects.*

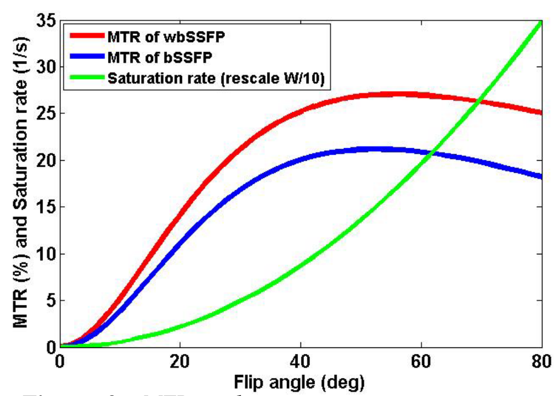

Figure 2: *MTR and mean saturation rate as a function of flip angle, for wbSSFP and bSSFP.*

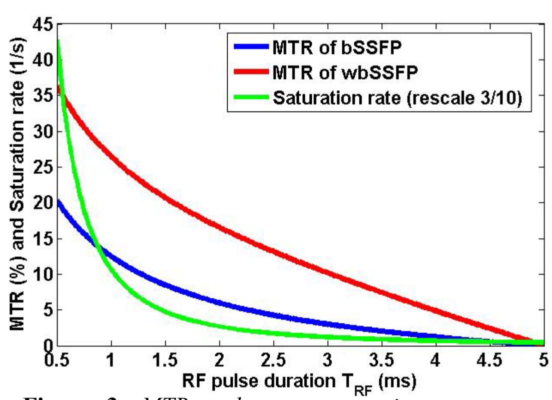

Figure 3: *MTR and mean saturation rate as a function of RF pulse duration with fixed (TR+TRs-2T_{RF}) for wbSSFP and fixed (TR- T_{RF}) for bSSFP.*